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# **Comparing GPS-based Indicators of Spatial Activity to the Life-Space Questionnaire (LSQ) in Research on Health and Aging**

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## **1. Introduction**

Research has shown that spatial activity such as mobility and environments people are exposed to are fundamentally important for the maintenance of physical and psychological health in old age (e.g., Seresinhe et al. 2015). Many of these findings, especially from the psychological and epidemiological domain, are originating from studies that relied on questionnaires (self-reports) such as the frequently used life-space questionnaire (LSQ) (Stalvey et al. 1999). The LSQ is an indicator for spatial activity, more specifically the spatial extent of an older person's mobility. It consists of increasing, but not equidistant, ordinal levels of spatial area (bedroom, home, yard, immediate neighborhood, town, beyond town). The LSQ as used in Baker et al. (2003) additionally assesses how often each life-space level has been attained during the 4 weeks preceding the assessment and whether any assistance was needed. The LSQ is associated with diverse factors contributing to health maintenance and independence of elderly people (e.g., Rantakokko et al. 2015).

Self-reports are subjective, usually retrospective or generalized responses and therefore risk being biased. Therefore, increasingly, health and aging researchers rely on GPS measurements as predictors of spatial activity (Chaix et al. 2013). Sensor-based assessment techniques such as GPS are a promising way to track "objectively" individuals' daily life activities. GPS devices are nowadays small and therefore relatively unobtrusive. They do not require any active engagement by the participants and offer the possibility of regular, high-density and longitudinal assessments (Kerr et al. 2012). It is necessary, however, to compute indicators that characterize spatial activity of an individual in order to make sense of the GPS data.

Consequently, the interesting question arises in which way and to what degree these sensor-based indicators compare to self-reported measures aiming at assessing comparable constructs. There is a wide range of research in the domain of physical activity that investigated the associations between sensor-based (objective, direct) and self-reported (subjective, indirect) measures (Prince et al. 2008). Within the spatial activity domain, mainly researchers from the field of transportation have compared how self-reported measures such as travel diaries compare to GPS-based measures (e.g., Shen and Stopher 2014). There is a range of methods to compute spatial activity indicators based on GPS data comparable to the LSQ (e.g., Patterson and Farber 2015). However, there is no research so far that compares GPS-based indicators to the LSQ. Therefore, our aim is, firstly, to come up with GPS-based indicators that approximate the concept of the LSQ, and, secondly, to compare the computed sensor-based indicators to the self-reported LSQ.

## 2. Data and Methods

### 2.1 Mobility, Activity and Social Interaction Study (MOASIS)

For the purpose of this research, we use GPS and LSQ data from the Mobility, Activity and Social Interaction Study (MOASIS). MOASIS collects individualized everyday-life health data in older adults. It started in August 2015 and ultimately aims to develop computational models to measure, analyze, and improve health behaviors and health outcomes in the everyday life of aging individuals. The study design of MOASIS includes baseline tests, self-reports, and an evening questionnaire, complemented by the ambulatory assessment of the physical (accelerometer), spatial (GPS) and social activity (microphone) with the custom-built sensor uTrail. The inclusion criteria for the participants of the MOASIS study are: aged 65 - 80 years, fluency in German and a score above 26 in the Mini Mental State Examination (MMSE) (Folstein et al. 1975) to set the minimum required cognitive ability (i.e., good mental and cognitive health). The main MOASIS study including approximately 150 participants will run from January 2017, but is preceded by two pilot studies testing the uTrail device, improving the measurement protocols and conducting the first two data collection campaigns. The preliminary analyses reported in this short paper are based on a small subset of the second pilot study, which took place from March–May 2016, in which 27 elderly individuals from the German-speaking part of Switzerland participated over a period of 30 days. Specifically, we used the GPS and LSQ data of four randomly selected participants with the IDs 10001 (23.03.–19.04.2016), 10005 (23.03.–19.04.2016), 10013 (24.03.–20.04.2016), and 10015 (24.03. –20.04.2016). The periods mentioned do not include the days when participants picked up and returned their devices at the lab, respectively.

### 2.2 Self-Reported LSQ Indicator

One part of the evening questionnaires consisted of an adapted version of the LSQ of Stalvey et al. (1999). Instead of retrospectively assessing the frequency with which life-space levels have been attained during the preceding 4 weeks as done in the study of Baker et al. (2003), participants filled the LSQ on a daily basis. The life-space levels were adapted to the Swiss context and consisted of eight levels as conceptually illustrated in Figure 1.

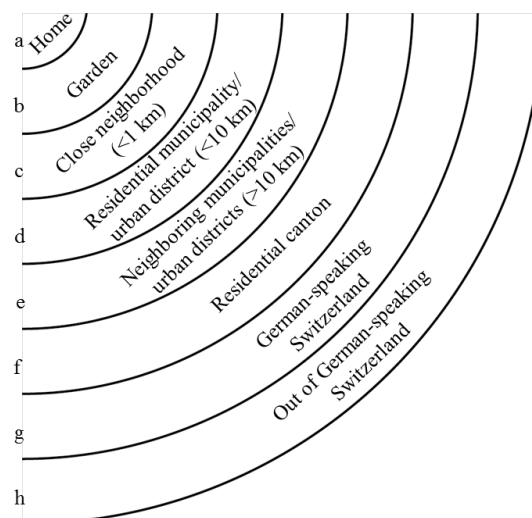


Figure 1. Conceptual model of LSQ levels.

Participants reported whether or not they have attained each of the life-space levels on that particular day. The question concerning, e.g., life-space level 7 was as follows: „Have you been to places within German-speaking Switzerland, but outside of your residential canton, today?“ The questionnaire was constructed such that theoretically all categories that are lying within the daily maximum attained category should have been attained as well. For these preliminary analyses, the category of the maximum life-space level attained per day approximated the self-reported daily life-space of a participant.

### 2.3 GPS-Based Spatial Activity Indicators

A first approach to approximate the daily life-space based on the GPS data consisted of computing the distance between the participant's home location and the daily most distant GPS location. The GPS data was recorded continuously with a sampling rate of 1 Hz. In order to exclude days with large gaps in GPS recording due to technical issues from further analysis, we determined a threshold, which defines the minimum number of GPS records required per day. The threshold corresponds to 75% of the median number of GPS records over the 28-day observation period for each participant. The home location for each individual was computed in two steps based on GPS data of valid observation days only: Firstly, we identified the coordinates of the first GPS fix of each day. The uTrail was programmed such that no data is recorded during charging. As participants were instructed to charge the devices overnight, the first GPS fix was usually obtained in the morning when the device was unplugged and as soon as enough satellites were received. Secondly, we defined the home location as the median latitude in conjunction with the median longitude of the beforehand defined first recorded coordinates of the separate days. Using the median is a simple method to exclude potential outliers. Subsequently, the most distant GPS point from the home location was identified and the corresponding distance was computed.

The second approach to approximate the daily life-space identifies the most distant LSQ category that was attained at each day. Table 1 shows how we have assigned the LSQ categories to increasingly distant areas around the home location of each individual such that they reflect the levels of the LSQ as closely as possible. Therefore, we defined distance buffers and the administrative unit boundaries provided by the Swiss Federal Office of Topography<sup>1</sup> in conjunction with data on the linguistic regions of each municipality provided by the Swiss Federal Statistical Office<sup>2</sup>. As questions e) and f) were not posed in a sufficiently discriminable way they were merged to one joint level 4. Likewise, levels a) and b) were merged, as it is impossible to reliably distinguish between home and garden solely based on GPS data. Subsequently, we assigned each GPS point the LSQ level within which it was contained. Eventually, for each day the maximum LSQ level achieved was extracted.

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<sup>1</sup> „swissBOUNDARIES<sup>3D</sup>“ edition 2015 LV95 LN 02, requested from: [http://www.toposhop.admin.ch/de/shop/products/landscape/swissBoundaries3D\\_1](http://www.toposhop.admin.ch/de/shop/products/landscape/swissBoundaries3D_1) (09.03.2015).

<sup>2</sup> „Die Raumgliederungen der Schweiz“ edition 01.01.2016, downloaded from: [http://www.bfs.admin.ch/bfs/portal/de/index/infothek/nomenklaturen/blank/blank/raum\\_glied/01.html](http://www.bfs.admin.ch/bfs/portal/de/index/infothek/nomenklaturen/blank/blank/raum_glied/01.html) (03.05.2016).

Table 1. Spatial definition of the LSQ levels.

No.	LSQ level	Spatially defined category
1	a) Home / b) Garden	Buffer of 100 m around home
2	c) Close neighborhood	Buffer of 1000 m around home
3	d) Municipality	Municipality that contains home
4	e) Neighboring municipalities / f) Residential canton	Canton that contains home
5	g) German-speaking Switzerland	German-speaking municipalities
6	h) Further away	Area beyond level 5

### 3. Preliminary Results

Figure 2 shows visualizations of the different life-space indicators for participant 10001. Figure 2a shows the distance to the daily most distant GPS point. The daily maximum distance varies a lot ranging from 0.1 to 70.9 km (on 25.03. and 26.03., respectively). A visual comparison of the distance-based spider diagram in a logarithmic scale with the spider-diagram of the LSQ categories (red line in Figure 2b) reveals a considerable resemblance between the two indicators. A quantitative comparison between distances and LSQ categories, however, is not directly feasible. In the following, we therefore focus on the comparison between the self-reported LSQ categories and the most distant LSQ categories identified based on the GPS points as displayed in Figure 2b. The map in Figure 2c shows the spatially defined categories for participant 10001 and makes visible in which categories the most distant GPS points are located. It must be noted, however, that the categories within which the most distant GPS points are located might deviate from the most distant LSQ category achieved by any of the other GPS points. This is true because not all of the spatial levels are equidistant buffers around a person's home (e.g., 28.03.).

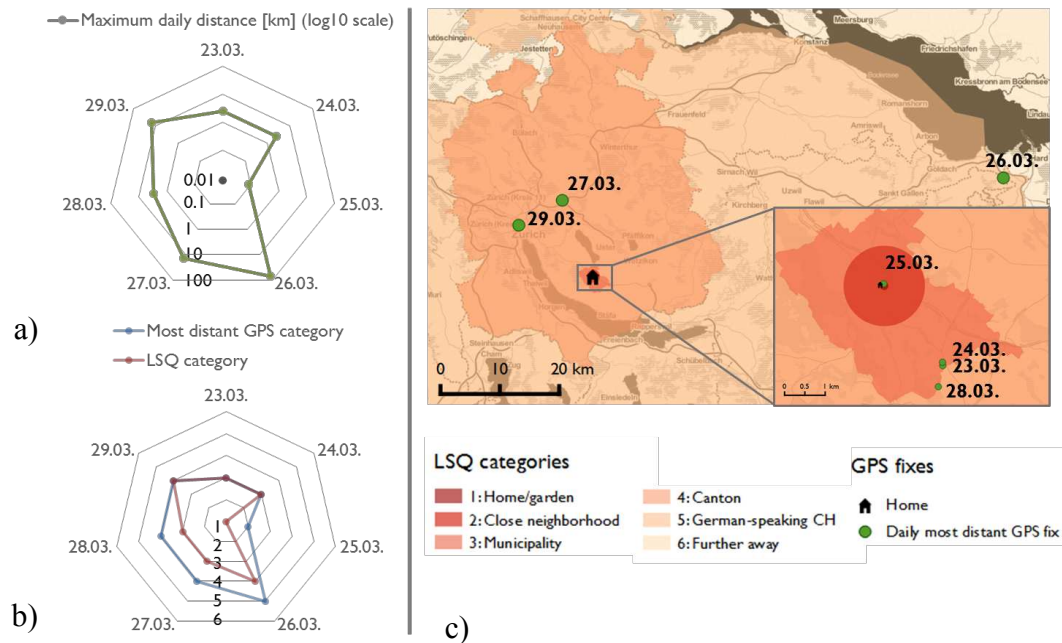


Figure 2. Visualization of the different life-space indicators of the first study week of participant 10001: a) Maximum daily distance from home in km on a logarithmic scale. b) Comparison of the daily self-reported and GPS-based LSQ category. c) Location of the daily most distant GPS points within the LSQ levels.

Figure 2b as well as the confusion matrix and the summary statistics regarding participant 10001 (Table 2) show that the GPS-based and the self-reported LSQ categories are corresponding to a large degree (50% overlap, average deviation of 0.6 categories). The average deviations for participants 10005, 10013, and 10015 are slightly higher with 0.7, 0.8, and 0.9, respectively. The percentage of correct estimates of participants 10013 and 10015 are also in a comparable range with 44% and 59%, respectively. The percentage of correct estimates of participant 10013 with 25%, however, is much lower. Overall, there is a clear tendency that people rather underestimate than overestimate the size of their life-space (29 to 75% overestimates versus 0 to 25% underestimates).

Table 2. Confusion matrix and corresponding summary statistics for the comparison of the self-reported and the GPS-based LSQ category for each participant.

10001		10005		10013		10015		Summary statistics				
GPS category	LSQ category	GPS category	LSQ category	GPS category	LSQ category	GPS category	LSQ category					
	1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6		1 2 3 4 5 6					
1	1	1	1	1	1	1	1	Total no. of estimates	16	16	16	17
2	1	2	1 4	2	1	2	1 1 1	Avg. deviation	0.6	0.7	0.8	0.9
3		3		3		3	1	Correct estimates [%]	50	44	25	59
4	1 6	4		4	1 10 4	4	1 4	Underestimates [%]	50	31	75	29
5		5	2 3 5	5		5	3 4	Overestimates [%]	0	25	0	12
6		6		6	1	6	1					

## 4. Conclusions and Outlook

In a next step, we will include all of the data of pilot study 2 in order to extend the current analyses and to find how well the different indicators correlate overall. In addition, we will examine whether there are systematic problems within the LSQ or the GPS-based indicators for the prediction of particular categories. Moreover, we will examine whether certain indicators work better for a particular group of participants (e.g., urban vs. rural resident). The insights of these analyses will contribute to the improvement of the LSQ that is going to be used in the main study starting in the beginning of 2017 (e.g., different questions for urban and rural residents or people living close to borders of administrative units).

Using the data of approximately 150 participants in the main study, it will be of great interest to investigate whether the above-stated trend for underestimation of the self-reported life-space holds true. We will also investigate the impact of the retrospective lag (daily vs. weekly vs. monthly LSQ) on the accuracy of the participants' estimation. In relation to this, we would also like to get a sense of how stable the different indicators are across different temporal scales (weekly, monthly, Mondays, etc.).

Furthermore, we would like to test alternative ways of characterizing people's life-space. Instead of assessing people's daily maximum range (as is done with the LSQ), it might be insightful as well to look at people's daily average distance from home which could give a more precise indicator on how much space was used. Moreover, a life-space indicator that takes into account which modes of transport have been used might be more meaningful in a health context (e.g., furthest distant point reached by active and passive transport). Further, we plan to compute measures that are aware of the area that has been covered and the time that has been spent at different locations by an individual.

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